DEVELOPMENT OF A SYSTEM FOR SURVEY OF RADON CONCENTRATION OF THE DAYTON AREA USING A LIQUID SCINTILLATION COUNTER AND ANALYSIS OF THE DATA

THESIS

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Preface

The purpose of this study was to set up a system to do a large scale survey and to analyze the data obtained from the survey. An equation for converting count per minute into radon concentration (pCi/l), a procedure for handling the vials, a survey form, and a database program were modified (from previous theses) or developed for this thesis. Two surveys were done during the course of the thesis. The system is in process of obtaining EPA's RMP Program's certification.

I would like to thank Dr. George John for his help. Without his guidance, portions of the system would not have been possible. I would also like to thank Bob Hendricks for helping me with my research and providing me with necessary equipment. The technicians of the Physics Department were very helpful in acquiring the necessary software and hardware for the system. Nancy, Diana, and Karen were there for me when I needed to get the survey forms ready. Finally, thanks to all the participants of my surveys.

Taewon Kim

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Abstract

The purpose of this study was to set up a system to do a large scale survey. The data obtained from the survey was analyzed. An equation for converting count per minute into radon concentration (pCi/l), a procedure for handling the vials, a survey form, and a database program were modified (from previous theses) or developed for this thesis. For equation of conversion, a calibration factor, an elution time constant, and adsorption time constant were calculated. The procedure for handling the vials underwent a major modification for this thesis.

Two surveys were done during the course of the thesis. On the first survey, the arithmetic average radon concentration with standard error of the mean was 2.9 ± 0.5 pCi/l. The geometric mean was 1.5 pCi/l with geometric standard deviation of 2.7 pCi/l. The EPA's action level of 4 pCi/l was exceeded by 16% of the samples. There were 85 samples taken during the first survey. On the second survey, with 156 samples, the arithmetic average and standard error of the mean was 3.8 ± 0.3 pCi/l. The geometric mean was 3.8 pCi/l with geometric standard deviation of 2.2 pCi/l. The EPA's action level of 4 pCi/l was exceeded by 29% of the samples. The second survey was done during winter using a modified survey

form. The results from both surveys indicated a log-normal distribution. The results for both surveys were obtained by using the database. The system is in process of obtaining EPA's RMP Program's certification.

DEVELOPMENT OF A SYSTEM FOR THE SURVEY OF RADON CONCENTRATION OF DAYTON AREA USING LIQUID SCINTILLATION COUNTER AND ANALYSIS OF THE DATA

I. Introduction

Purpose

The goal of this thesis was to set up and test a system for measuring radon concentrations in a large scale survey. A large scale survey of the Dayton area for radon concentration and the analysis of the data obtained in the survey are parts of the goal.

Previous Research

Three theses needed for this research were "Development of Techniques to Relate Radon Levels in Homes in the Dayton Area to Local Geology and Fill Material" by Bouchard (2), "Evaluation of Three Passive-Integrating Charcoal Detectors for Measuring Radon Concentrations" by Sharp (10), and "Development of a System to Perform, Record, and Analyze Measurements of Radon Concentrations on a Large Scale" by Pierce (8).

Bouchard used charcoal canisters similar to those developed by Cohen to measure the radon concentration in the homes of the Dayton area (2:9). The arithmetic mean with standard error of the mean were 6.22 $\pm$ 0.68 pCi/l in the first floor and 11.6 $\pm$ 1.3 pCi/l in the basement. He sampled 107 first floors of residences and 75 basements. Plots of the cumulative frequency distribution vs radon concentration on log-probability paper produced a straight line, indicating a log-normal distribution (2:21). The geometric means and standard deviations that he observed are 3.7 $\pm$ 2.9 pCi/l for first floor and 6.7 $\pm$ 3.4 pCi/l for basements.

Sharp studied three types of radon detectors. Two detectors were charcoal canisters and the third was a liquid scintillation (LS) vial. All the detectors are based on charcoal. Sharp set up a protocol for measuring radon using LS vials. The analysis of the vials were done on Packard Tri-Carb 2200CA Liquid Scintillation Analyzer. To calculate radon concentration in pCi/l from net counts per minute, Sharp found the conversion factors needed. He used Bouchard's radon chamber to find the saturation time for the LS vials (10:35).

Finally, Pierce started to set up a system for a large scale survey of radon concentration. He used one of Sharp's protocol for calculating the radon concentration. Using the conversion factors, he used a database program for instant calculation of radon concentration. The program was set up to

allow the user to enter the data from the survey questions. The survey form was adapted from EPA's radon survey questionnaire of 77 questions with sub-questions (12). Pierce's survey form contains 26 questions (8:46).

Scope of Thesis

This thesis continues the work begun by Sharp and Pierce to develop a system and methodology for conducting a large scale surveys of radon concentration in residences and the work place. In particular their work was modified to correct and improve the analytical procedures, the collection of pertinent data, the establishment of a large database to allow storage of large amount of information and to find correlations between radon concentration from which correlations can be extracted between a variety of residential and environmental factors and observed radon concentrations. This thesis presents modifications to the protocol for measuring and analyzing radon concentrations, the development of an improved equations for converting counts from the LS vials to pCi/l, selection of a new database program, modification of old survey form, testing of the system with data obtained from two surveys, participation in a Quality Assurance program, and initiating contacts for certification by the EPA.

Sequence of the Thesis

The report is arranged in chapters. Chapter II contains the background information associated with radon. Chapter III describes the equipment used in this thesis. Chapter IV describes the experiment involved in calculating the radon concentration. The quality control programs associated with the experiments are contained in this chapter. Chapter V deals with the selection and the development of the database. The results from the experiments and the survey are contained in Chapter VI. Chapter VII contain the conclusion from the research as well as the recommendation for further studies.

II. Background

Radon and Its Daughters

Radon is a noble gas. It is a colorless, odorless, and tasteless monatomic gas. This noble gas can form compounds like clathrates and fluorides (3:1). However, for all practical purposes, it is considered inert. Radon occurs naturally and has properties of both metal and nonmetals. The 3 isotopes that occur naturally are ^{219}Rn, ^{220}Rn, and ^{222}Rn. The ^{219}Rn is part of ^{235}U-Actinium series with half-life of 4 seconds. The ^{220}Rn is part of ^{232}Th series with half-life of 55.6 seconds. Finally, ^{222}Rn is part of ^{238}U series with half-life of 3.82 days.

In a study of radon concentration, only ^{222}Rn is considered. The time needed for radon to diffuse out into the environment is met only by ^{222}Rn. The ^{219}Rn and ^{220}Rn have half-lifes that are less than a minute, which does not give them enough time for the short-lived isotopes to diffuse out in a large amount (1:8). Term "radon" will refer to ^{222}Rn in this thesis unless otherwise noted.

The alpha decay of ^{226}Ra from the ^{238}U series form ^{222}Rn. The properties of ^{222}Rn and its progeny are listed in Table 1 (8:10).

Table 1. Decay of Radon and Its Progeny

^{222}Rn Decay Energies and Percentages							
Nuclide	Half-life	alpha		beta		gamma	
		MeV	%	MeV	%	MeV	%
^{222}Rn	3.824 d	5.49	100	-	-	-	-
^{218}Po	3.05 min	6.00	100	-	-	-	-
^{214}Pb	26.8 min	-	-	0.65 0.71 0.98	50 40 6	0.295 0.352	19 36
^{214}Bi	19.7 min	-	-	1.00 1.51 3.26	23 40 19	0.609 1.120 1.764	47 17 17
^{214}Po	163.7 fs	7.69	100	-	-	-	-

The radon hazard is not from the decay of radon itself, but the decay of its progeny. The progeny can attach itself to aerosols or get deposited on surfaces. If the progeny is attached to aerosols, they are stopped before entering the lung. The main concern occurs when the progeny gets deposited in the lung itself, especially in the upper respiratory tract. There is no concern if the progeny gets deposited on external surfaces. The ^{218}Po and ^{214}Po causes the most harm.

The radon hazard is usually concerned with an enclosed area. The sources of radon in an enclosed area, like buildings or mines, are from soil, building material, water, and natural gas. Radon is in all rocks and soil in different levels.

Units of Measurement

Concentrations of radon are reported in a variety of units among which are pCi/l, Bq/m^3, and working level. In this thesis pCi/l is used; however for comparison with other uses, the relation between these units is presented.

$$1 \text{ pCi} = 3.7 \times 10^{-2} \text{ Bq}$$

$$1 \text{ liter} = 10^{-3} \text{ m}^3$$

$$1 \text{ pCi/l} = 37 \text{ Bq/m}^3$$

Concentration of radon can also be inferred by measuring concentration of radon progeny in terms of working levels (WL). One WL is defined as "130,000 MeV of alpha-particle kinetic energy per liter of air (9:25)." The WL can be calculated using Equation 1.

$$WL = 0.00105C1 + 0.00516C2 + 0.00379C3 \qquad (1)$$

WL = number of working levels
C1 = concentration of ^{218}Po in atoms per liter
C2 = concentration of ^{214}Pb in atoms per liter
C3 = concentration of ^{214}Bi in atoms per liter

The measurement of WL is difficult since concentration of ^{218}Po, ^{214}Pb, and ^{214}Bi need to be found. The WL reflects the biological hazard of the progeny.

Factors Affecting Radon Concentration

To measure radon, some of the factors that affects the radon concentration must be considered. The radon

concentration is spatially dependent. The variety of sources presented in the environment causes the difference of radon concentration. The sources include soil, natural gas, water supply, and building material. In addition to the difference of radon concentration in different regions of the world, there is a difference in different location of the individuals' home. A New York State study found radon concentration in the basements to be 2.5 times larger than other parts of the house (11:45).

A study has also shown that the radon concentration changes with time. A study done in New Jersey shows the fluctuation in radon concentration with time (11:44). The test was done between the months of September and July. The fluctuation is primarily due to changes in weather condition.

Three factors people can use to control radon concentrations in their homes are entry rate, ventilation rate, and removal or transforming radon or its progeny. These factors have great influence in indoor radon concentration.

Measurement Techniques

Methods. There are a variety of methods to measure radon and its progeny. The methods can be divided into three groups. They are instantaneous, continuous, and time averaging. The instantaneous or grab method is used for short term measurements. The continuous or real time method is for

monitoring samples continuously. This method is used for investigation of time-dependent behavior of radon and its progeny (11:72). The time-averaging method is used for long term measurements to find the average radon concentration over a long period of time.

All the methods can also fall into two categories depending on their method of collecting radon and its progeny. An active technique draws in the radon and its progeny for detection while passive technique requires diffusion of radon and its progeny.

Liquid Scintillation Counting. This thesis used the integrating and passive method to determine radon concentration. In this method, a container holding activated charcoal and desiccant is exposed to the environment. The activated charcoal absorbs the radon while the desiccant absorbs the moisture. The charcoal can absorb the water but the desiccant absorbs the water preferentially. After exposing the charcoal and the desiccant to the environment for a period of time, a scintillation cocktail is added without "wetting" the charcoal. The radon diffuses from the charcoal and dissolves in the solvent where it decays. The energy from the decay is absorbed by the solvent which transfers it to the solute through collisional interaction. The solute de-excites to release photons that are detected by a photomultiplier tube (PMT).

III. Equipment

Liquid-Scintillation Analyzer

A Packard Tri-Carb 2200CA Liquid Scintillation Analyzer was used for measurements. The analyzer is "designed for quantitative detection of alpha, beta, and gamma radiation, and various types of luminescence (bioluminescence and chemiluminescence) (7:1-4)." The analyzer uses coincidence counting which compares the output from two PMTs between which a sample is placed. In a nuclear decay, 10 photons are produced for every keV of energy deposited (5:1-13). This energy is dissipated in about 5 ns so that a decay would stimulate both PMTs at the same time.

The vials used for sampling are held by a Varisette cassette which holds up to 12 vials. Each Varisette has an identifier called Protocol Flag. The identifier represents instruction called protocol which the analyzer uses when counting the vials. The protocol for counting radon in the analyzer is presented in Appendix A.

Vials

The vials used in this study were developed by L. Grodzin and manufactured by NITON Corp (6). These polyethylene vials are 2.5 inches tall and 1 inch in diameter and weigh approximately 14.9 grams. As shown in Figure 1, a plastic

basket is attached off center to the top edge. This basket which contains 1.25 ± 0.5 grams of activated charcoal and 1.75 grams of silica gel desiccant, has a perforated plastic cover that serves as a diffusion barrier for radon absorption. Each vial is sealed with a cap which is removed only when the vial is used to absorb radon.

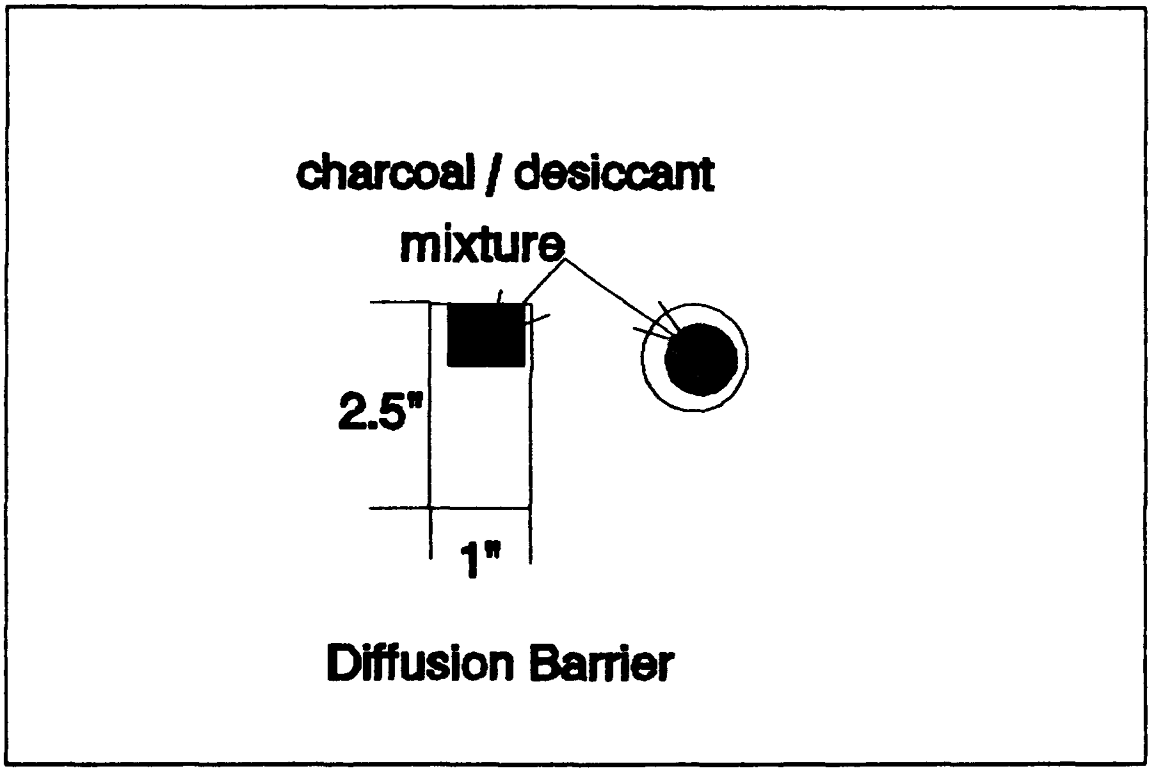

Figure 1. View of Pico-Rad Vial

Radon Chamber

The chamber was originally started by Bouchard for his thesis. The chamber is a 250 liter glovebox. It contains a

radon source, an aquarium pump, and a fan. The top view of the chamber is in Figure 2.

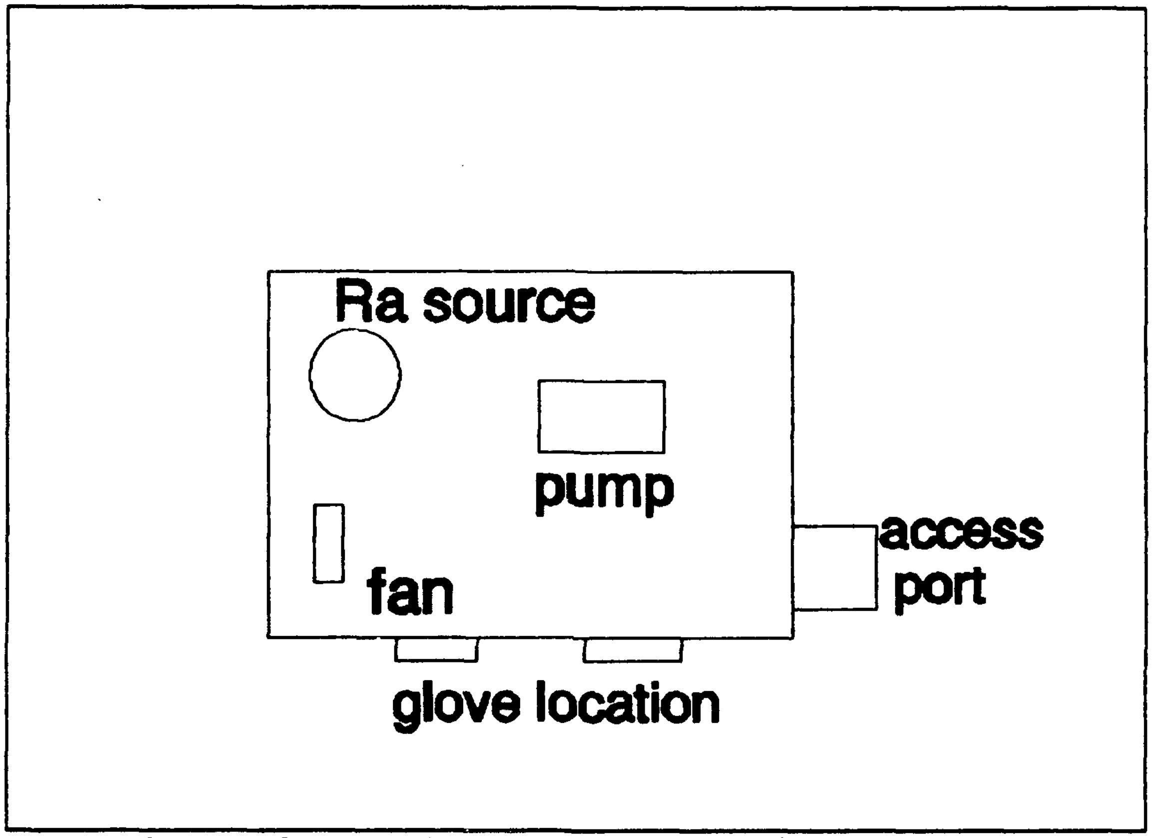

Figure 2. Radon Chamber in Building 470

Randy Wharton modified the chamber to control and monitor its environment (14). The chamber is now set up to monitor radon concentration, temperature, relative humidity, and barometric pressure. The radon concentration and temperature can be controlled (14:3). A reservoir source for radon is 100 µCi ^{226}Ra dissolved in a 4-normal hydrochloric acid. This source contained in a shielded stainless steel vessel is used to inject radon as need into the chamber.

Barrier

A barrier was set up inside the radon chamber to reduce the air movement. Without the barrier, the radon accumulation reached saturation in a shorter period of time. To simulate the testing conditions inside the chamber, the vials were placed under the barrier. The transparent plastic draft shield is a 6" X 12" X 24" box, with an open bottom and a cut away section at the 6" X 12" ends as shown in Figure 3.

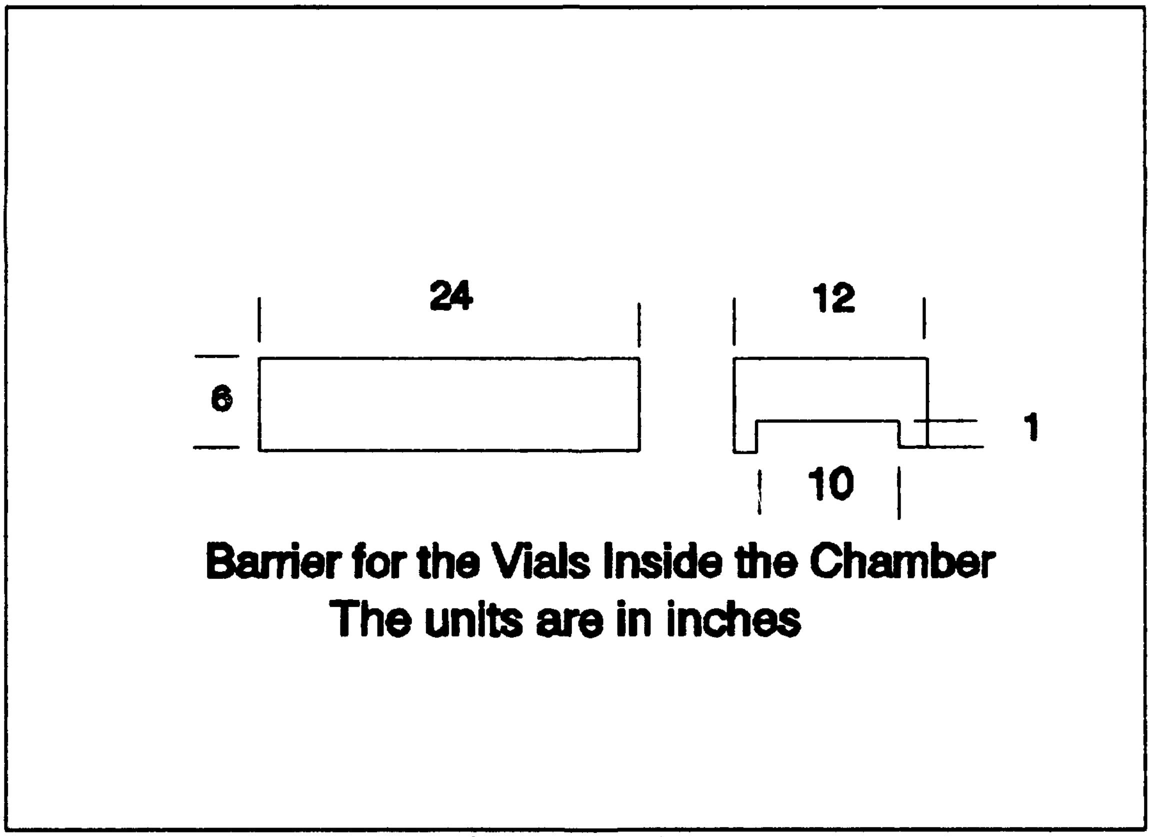

Figure 3. Side Views of the Barrier

IV. Experimental Method

Standard Protocol for Measurement of Radon

A procedure for measuring radon, based on previous research and the equation of conversion, is necessary for establishing a system for a mass survey. The procedure takes into an account the elution time, exposure time, calibration factor, and conversion equation. Each segment of the procedure is important to the protocol.

Adsorption Time Constant. The adsorption time constant τ_A is associated with the exposure time of the vial. The saturation of the vial follows an exponential curve. The cumulative adsorption function is in the form of $1 - \exp(-t/\tau_A)$. τ_A was needed since the time for 100% accumulation of the radon could not be reached in a short period of time. To find the adsorption time constant τ_A, a plot of exposure time vs percent adsorption was used. The AFIT radon chamber was used in the experiment in which vials were exposed for different length of time and then counted using the LS counter after an appropriate elution time.

Elution Time Constant. An elution time constant τ_E is associated with the time between addition of the LS cocktail and counting of the vial in the LS counter. The radon in the charcoal is eluted into the cocktail at a set rate. For the experiment, two vials were exposed in the radon chamber for 48

hours. The cocktail were then added. A seperate plot of elution time vs counts per minute for room temperature and internal LS counter temperature was used to find τ_B. Since amount of cocktail added to the vial can also affect the elution time constant, 10 ml of cocktail were used for all experiments to minimize the affect.

Calibration Factor. In addition to τ_A and τ_B, the calibration factor was calculated. The calibration factor CF takes into account all other factors involved in conversion, like the counting efficiency. The CF was calculated using a known source of radon concentration. Counts per minute was compared to that of the radon concentration. The decay factor and adsorption time was taken into account in calculating the calibration factor.

Equation of Conversion. The equation of conversion converts counts per minute to pCi/l. The equation for LS is similar to that of charcoal canister's conversion equation. The conversion equations used by most researchers are similar. An equation used by EPA for charcoal canister is :

$$C=\frac{NCR}{CF\,t_s\,\epsilon\,DF} \qquad (2)$$

Equation 2 was defined by A. C. George. It is one of the most

used charcoal canister equation (4:131). Another equation used by researchers (Watson and Blue) is :

$$C = \frac{NCR}{CFDF} \tag{3}$$

In the Equations 2 and 3,

C	=	average radon concentration
NCR	=	net count rate
CF	=	calibration factor
t_s	=	sampling time
ϵ	=	counting efficiency
DF	=	decay factor = $\exp[-\lambda(t_s/2 + t_l)]$
λ	=	decay constant for radon
t_l	=	time from end of sampling time to beginning of count

Watson and Blue combine sampling time and counting efficiency into their CF. However, Watson and Blue do not use the same DF. Watson, like EPA, used decay time from middle of sampling time to beginning of counting time. Blue used decay time from end of sampling time to beginning of counting time. He did not use DF = $t_s/2 + t_l$, he used DF = $\exp(-\lambda t_l)$ (4:132).

Net count rate, calibration factor, and decay factor from Equation 2 and 3 were used in this thesis' conversion equation. In addition, equation containing the sampling time (i.e. exposure time) of air and elution time for the cocktail

was also explored. The equation containing exposure time was used while the equation for elution time was left out.

Survey of the Dayton Area

With the protocol for measuring radon, surveys were conducted. A survey for each household consists of two vials and a questionnaire form. The survey was accomplished by handing out the vials and forms randomly in the school. Two surveys were accomplished for this thesis. First survey was to test the procedure for measuring the radon concentration and to the test questionnaire made by Pierce. The second survey incorporated the modified procedure for measurement and the questionnaire.

Quality Control

Quality control is needed to insure that the protocol for the analysis of the LS vials and the results of the vials are accurate as possible. To insure the accuracy of the analysis, two different programs are being pursued. The programs are by NITON Corporation and EPA.

NITON's Quality Assurance Program. The Quality Assurance (QA) program by NITON consists of monthly tests. NITON sends four vials on the first week of the month for analysis. The results from the participants are then compared to that of the NITON's control group. The control group

consists of 10 vials that are analyzed by NITON. The mean and the standard deviation is given at the beginning of the next month's test. If the results are different from that of the control group, the discrepancy is investigated.

EPA's Radon Measurement Proficiency (RMP) Program. The RMP program was set up to provide consumers with a list of organizations who have passed the EPA's set standard. The RMP program provides organizations an opportunity to demonstrate their proficiency in measuring radon. The RMP program lends the radon measurement procedure credibility. The part of the program that is of interest to this thesis is the radon measurement test. After the acceptance of the application, the test begins by sending four vials to EPA. EPA testing center will expose the vials and send them back for analysis. To pass the test, the results must have an error of less than 25% for each of the vials. If one or more of the results in an error greater than 25%, but less than 50%, a retest is possible. However, if one or more of the results have an error greater than 50%, a partial reapplication is necessary with an explanation of the problem for the previous test. A corrective action and the calibration procedure must also be provided. If EPA does not receive the partial reapplication within six months, a complete reapplication is necessary.

V. Data Analysis

Selection of Database

Previous research used dBase III Plus for mass survey. However, the program developed for dBase III did not analyze the data from survey questions. Pierce realized that there are too many variables involved in finding correlations. To find some correlations, a question of upgrading the program from the dBase III Plus or using another database package was considered.

The dBase III Plus has no easy graphic's or other types of capabilities to display correlations. A sub-program could be written to display correlations. However, the sub-program could be hardwired into the main program. It would severely limit the number of correlations since each correlation would require a program. However, dBase III Plus has some advantages. The database was already on hand for immediate use and a program to accept the answers from the survey was already written. The dBase also has its own language for adaptability. The adaptability is also a disadvantage, since the exploration of the correlations would require extensive programming.

Another database, Reflex by Borland, was considered to replace dBase III Plus. Instead of writing a program to accept the answers from the survey questions, a user can

define a structure to accept the answers. The time required to add or delete a survey question is negligible. The structure of the database can easily be modified as changes occur. Another advantage of Reflex is its ability to easily display simple correlations from the survey in a graphic format. Reflex requires few key strokes to display the simple correlations. For correlations between several survey questions, Reflex has cross tabulation capabilities. The cross tabulation allows the user to look for correlations involving more than one question at a time from the survey.

After entering the data from the survey into the database, a reply letter is sent to the participants. A form letter, developed for this thesis, is sent to the individuals taking the survey. The replies for high radon concentration and low radon concentration are in Appendix B and C.
The information in the reply letters are as recommended by the EPA (13). The user's guide for Reflex, in Appendix D, tells the user how to modify the structure of the database, enter the data, and display the correlations from the data.

Development of the Survey Form

A survey form is used to obtain information of the testing site. The survey form used in this study is a modification of the one that Pierce developed from a longer, more detailed, form prepared by the EPA. Modifications to

Pierce's form was made after receiving feedback from participants of the first survey. Since the feedback showed that some participants did not read the long instructions, it was made more concise and presented in "bullet" format.

In addition to the change of the instruction in a "bullet" format, it now includes the specific locations for the placement of vials. The instruction page also asks for the address (including city and ZIP code). This part is necessary to compare the radon concentration in different areas of Dayton.

The original survey form was prepared for surveying of buildings and laboratories at Wright Patterson AFB. The new form is now formatted for residential usage. Some questions that were added to the survey concerns electrostatic air filter, insulation, and humidifier. Some of the questions were modified and/or reworded to clarify their meanings and to make them more suitable for Reflex usage. The new survey form is in Appendix E.

VI. Results

As noted in the experimental chapter, the equation for converting count rate obtained from the radon vials to concentration of radon requires the absorption time constant, the elution time constant, and the calibration factor. These results are presented in this chapter. Using the results lead to a standard protocol for measurement of radon. The results from the surveys and Quality Assurance program are also presented in this chapter.

Standard Protocol for Measuring and Disposing of Radon Vials

The protocol for measuring radon starts with the participants of the test receiving two vials. The vials are exposed for 48 hours and returned for analysis as soon as possible. The exposure time for the vials is within the guidelines set by NITON; as well as meeting the standard set by EPA for their test program. After receiving the vials back, 10 ml of LS cocktail (Insta-Fluor) is added. Addition of InstaFluor must be done in an approved hood since the InstaFluor contains xylene. Laboratory animals have contracted liver cancer when they were exposed to xylene fumes (8:70). After elution time of 18 hours, the vials can be counted by the LS Analyzer. The results from the analyzer are

then entered into the Reflex program to obtain the radon concentration in Pci/l.

The vials should be properly disposed after the analysis. InstaFluor should be emptied into a waste container inside the hood after analysis of the vials. The empty vials should then be cleansed with 2 ml of toluene and emptied into the waste container. The cleansed vials should be left open inside the hood to dry for two to three days before disposal. The waste container with InstaFluor and toluene is left inside the hood to dry. The residue should be disposed as chemical waste in accordance with Air Force regulations.

Adsorption Time Constant. The exposure time of 48 hours was set after examining previous research, current data from NITON, and doing experiments at AFIT. In previous research, Sharp reported that the radon vials saturated in 24 hours (10:35); which disagrees with the reported value of over 48 hours from NITON (6:52). Sharp used the AFIT radon chamber and plotted exposure time vs cpm to determine his saturation time. The disparity between Sharp's experimental result and the reported value was caused by the fan in AFIT's radon chamber. The fan caused the radon in the chamber to enter the vials at a rate faster than natural diffusion by disturbing the radon chamber's environment. To correct for the disparity, a barrier was placed over the vials during the experiments.

In calculating the adsorption time constant, a plot of length of exposure of vials to radon in the AFIT chamber vs counts per minute is presented in Figure 4. Analysis of this data shows that it follow the expected exponentially limited uptake given by Equation 4.

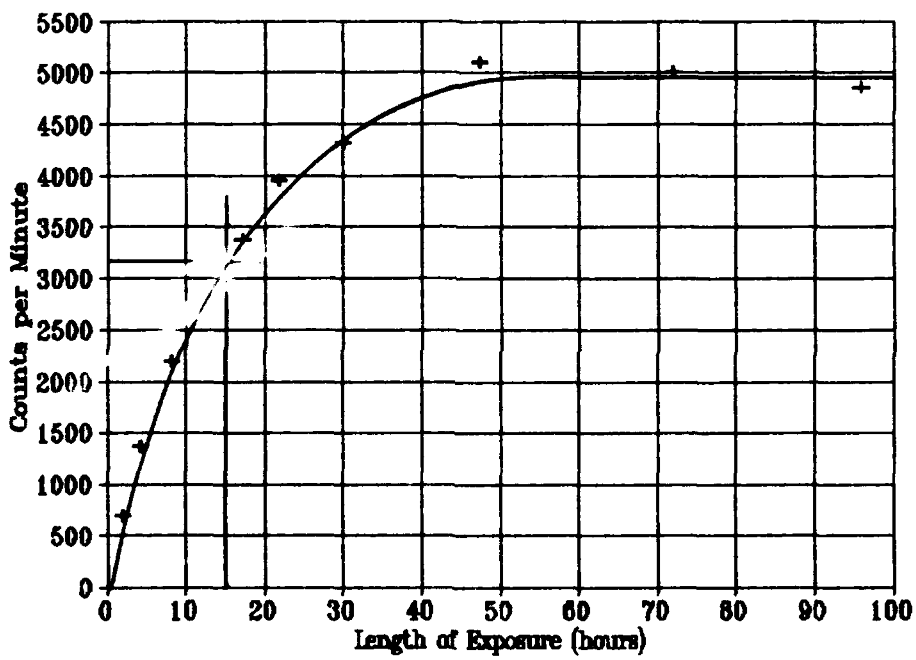

Figure 4. Exposure Time Vs Counts per Minute

The adsorption time constant (τ_A) of 15 hours was analytically calculated using Equation 4. τ_A of 15 hours was obtained

$$1-e^{-\frac{t}{\tau_A}} \qquad (4)$$

using the three largest count rates as the maximum count rate for the curve. In addition to analytical analysis, the constant was graphically confirmed. The discrepancy of the reported value and experimental constant can be attributed to the nonquiescent condition of the AFIT's radon chamber (6:52). τ_A of 18 hours was used in this thesis instead of 15 hours since the "problem" of the radon chamber could not be fixed.

Elution Time Constant and Its Equation. For the calculation of the elution time constant τ_E, 10 ml of scintillation cocktail was added to the vials exposed in the radon chamber. The vials were than periodically analyzed using the LS Analyzer. A plot of elution of time vs count rates of the vials are in Figure 5 and Figure 6. In room temperature, τ_E was approximately 1.6 hours. Inside the LS Analyzer, where temperature is cooler, τ_E was approximately 2.5 hours. The constants were analytically and graphically determined. For the analytical calculation of τ_E, Equation 5 and the maximum count rate of each vials were used. The operation manual for Pico-Rad Radon Analysis Software reported τ_E of 2 hours. The manual recommends not counting the vials for at least 6-8 hours after addition of the cocktail (6:53).

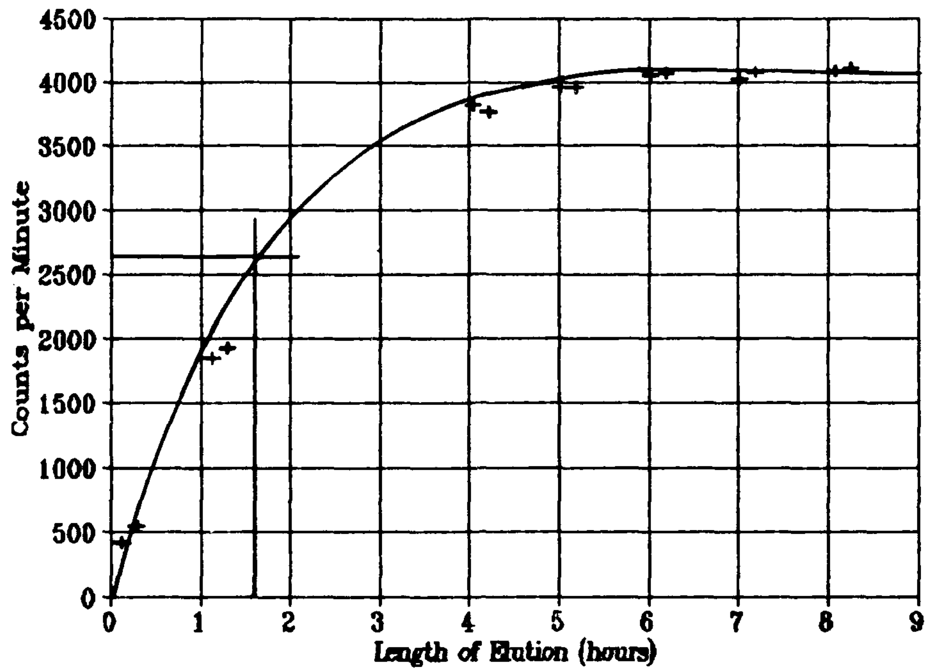

Figure 5. Elution Time vs Counts per Minute at Room Temperature

$$1-e^{-\frac{t}{\tau_E}} \tag{5}$$

To take out the dependence of elution time and minimize the error in the equation of conversion, the equation involving τ_E was not directly used. To eliminate the elution time

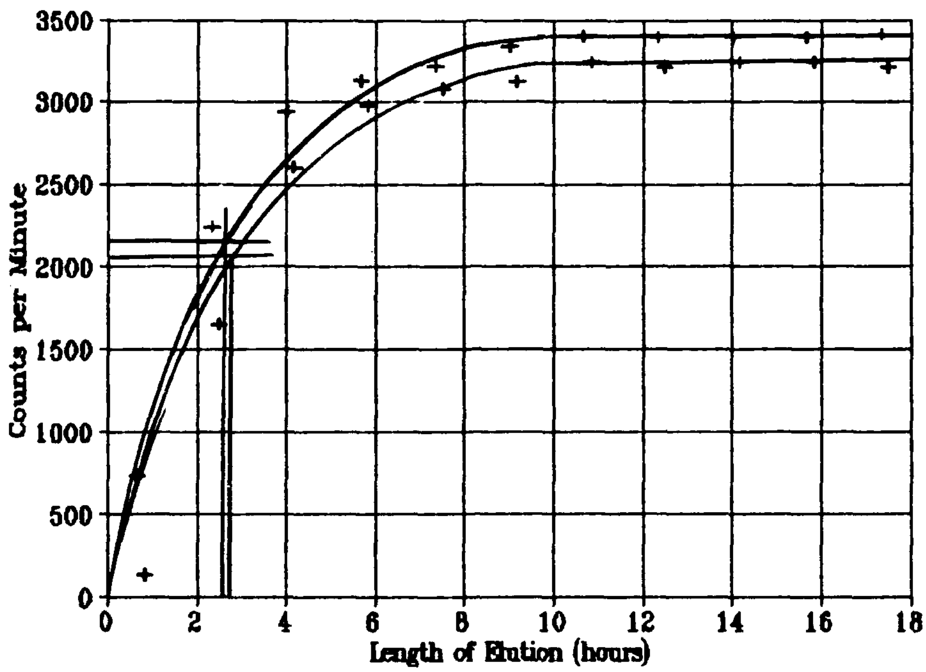

Figure 6. Elution Time vs Counts per Minute at LSC Temperature

dependence from the equation of conversion, the vials are not counted until elution time of at least 18 hours has elapsed. In 18 hours, more than 99% of the radon would have dissolved into the cocktail, even if τ_I equalled 3 hours. By eliminating Equation 5, the equation of conversion would also be simplified. The main reason for the removal of Equation 5 was to reduce error in calculating the radon concentration.

Equation of Conversion. The results from the elution time constant and adsorption time constant experiments in conjunction with conversion equation for charcoal canisters and the operation manual for PICO-RAD Radon Analysis Software lead to Equation 6.

$$C=\frac{CF*NCR*e^{\lambda t_1}}{1-e^{-\frac{t_s}{\tau_A}}} \qquad (6)$$

where

C = average radon concentration (pCi/l)
NCR = net count rate (cpm)
CF = calibration factor (pCi/l / cpm)
λ = decay constant for radon (hours)
t_s = survey exposure time (hours)
t_l = time from end of exposure to beginning of count (hours)
τ_A = adsorption time constant (hours)

The equation involving elution time constant was not directly used in this thesis. The elution time constant is imbedded in the protocol for measuring radon concentration.

Calibration Factor. After obtaining the adsorption ,the elution time constant, and the equation of conversion, the calibration factor was needed to finish building the equation for converting count rates to radon concentration. The first approximation of the calibration factor (CF) was made using

the AFIT radon chamber. The exposed vials from the radon chamber were sent to NITON Corporation for the analysis of radon concentration in the chamber. NITON is listed by the EPA's as passing their RMP program. Of eight vials exposed in the chamber, four were sent to NITON and four were analyzed by the LS Analyzer. The average radon concentration reported from NITON and average cpm from the analyzer were used to calculate CF using Equation 6. The calibration factor was calculated to be 0.02465 $\pm$ 0.00067 pCi/l/cpm. The vials used in this experiment were exposed in the radon chamber for 48 hours and taken out on 11:50 A.M. September 24 1991. The vials were then eluted for 24 hours and analyzed on 12:18 P.M. September 25 1991. The uncertainty of CF was calculated using uncertainty of the reported radon concentration and cpm in a quadrature. The reported values from NITON and the LS Analyzer with their uncertainties are listed in Table 2.

Table 2. Results of AFIT Radon Chamber's Concentration From NITON and Results of Radon Chamber's Count Rate Using AFIT's LS Analyzer

Vial's S/N	Radon Conc. (pCi/l)	Vial's S/N	Count Rate (cpm)
320425	114.1 $\pm$ 1.3	320073	3916.7 $\pm$ 19.8
320896	120.9 $\pm$ 1.3	320754	3695.3 $\pm$ 19.2
320341	115.1 $\pm$ 1.3	320201	3529.0 $\pm$ 18.7
320622	121.0 $\pm$ 1.3	320390	3678.1 $\pm$ 19.1

The statistical results of Table 2 are :

Radon concentration:

average	=	117.8	pCi/l
standard deviation	=	3.7	pCi/l
standard error of the mean	=	1.9	pCi/l

Count Rate:

average	=	3704.8	cpm
standard deviation	=	159.8	cpm
standard error of the mean	=	79.9	cpm

Second CF, 0.02525 $\pm$ 0.00065 pCi/l/cpm, was calculated using QA Program's results from NITON. This time, four vials from a known radon concentration were analyzed. The known radon concentration and the analyzer's results were used in Equation 6 to calculate the CF. In this experiment, NITON exposed the four vials in their own chamber for 48 hours, from 9:37 A.M. November 2 to November 4 1991. NITON calculated the radon concentration to be 25.3 $\pm$ 0.4 pCi/l. The count rates and uncertainties, analyzed on 2:18 P.M. November 6 1991, are in Table 3.

Table 3. Net Count Rate of 4 Vials Sent by NITON

Vial's S/N	Net Count Rate (cpm)
371056	617.1 $\pm$ 8.0
371025	632.9 $\pm$ 8.1
371024	593.5 $\pm$ 7.9
370984	653.9 $\pm$ 8.2

The statistical results are :

average net count rate	=	624.4 cpm
standard deviation	=	25.5 cpm
standard error of the mean	=	12.8 cpm

Quality Control

Two sets of program for quality control were instigated after formulating the equation of conversion and standard protocol for measuring radon concentration, they are NITON's Quality Assurance Program and EPA's Radon Measurement Proficiency Program.

NITON's Quality Assurance (QA) Program. The QA program started in October of 1991. NITON sent four vials to be analyzed using the conversion equation. NITON reported the following results for QA vials exposed from 10:45 A.M. October 5 to October 7 1991 :

NITON control group results :

N	=	10 vials
Mean reading	=	24.2 pCi/l
Standard deviation	=	1.0 pCi/l
Standard error of the mean	=	0.3 pCi/l

AFIT results :

N	=	4 vials
Mean reading	=	24.9 pCi/l
Standard deviation	=	2.1 pCi/l
Standard error of the mean	=	1.1 pCi/l

The vials from NITON were analyzed on 3:37 P.M. October 9 1991. The October results from the analyzer and conversion equation are in Table 4.

Table 4. Count Rate and Radon Concentration of the Vial's Sent by NITON for Quality Assurance Program in October 1991

Vial's S/N	Net Count Rate cpm	Radon Concentration pCi/l
389256	490.7 ± 7.0	23.3 ± 0.7
389670	522.6 ± 7.2	27.7 ± 0.8
389652	560.7 ± 7.5	23.4 ± 0.7
389615	511.2 ± 7.2	25.0 ± 0.7

NITON reported the following results for QA vials exposed from 9:37 A.M. November 2 to November 4 1991:

NITON control group results :

N = 10 vials

Mean reading = 25.3 pCi/l

Standard deviation = 1.2 pCi/l

Standard error of the mean = 0.4 pCi/l

AFIT results :

N = 4 vials

Mean reading = 24.7 pCi/l

Standard deviation = 1.0 pCi/l

Standard error of the mean = 0.5 pCi/l

The vials from NITON were analyzed on 2:28 P.M. November 6 1991. The November results from the analyzer and conversion equation are in Table 5.

Table 5. Count Rate and Radon Concentration of the Vial's Sent by NITON for Quality Assurance Program in November 1991

Vial's S/N	Net Count Rate CPM	Radon Concentration pCi/l
371056	617.1 ± 8.0	24.3 ± 0.7
371025	632.9 ± 8.1	25.0 ± 0.7
371024	593.5 ± 7.9	23.5 ± 0.7
370984	653.9 ± 8.2	25.9 ± 0.8

EPA's Radon Measurement Proficiency (RMP) Program. EPA has accepted AFIT's application and AFIT is in middle of the testing program.

First Survey of Dayton Area for Radon Concentration

The purpose of the first survey was to test the procedure for measuring radon and the survey form. The first survey was done using the survey form developed by Pierce in his thesis. There were 85 samples taken from the Dayton area.

Comparison to Previous Survey Done by Bouchard. A comparison was done to examine the similarities and the differences between Bouchard's survey and this thesis's survey. Bouchard's survey was done using charcoal canisters

and were based on three days exposure, compared to two days exposure for this thesis (2 : 9). Bouchard reported average radon concentration for the basement, first floor, and regions of Dayton area. He also observed a log-normal distribution of the measurements (2:21). Table 6 contains the comparison of the basement's, first floor's, and second floor's results. The results are arithmetic average with standard deviation.

Table 6. Comparison of First Survey and Bouchard's Survey by Location of Vials in the Participants' Homes

Location of Vials	Survey One's Results (pCi/l)	Bouchard's Results (pCi/l)
Basement	2.2 / 0.5	11.6
First Floor	3.4 / 0.7	6.22
Second Floor	1.9 / 0.5	-

The first survey had 13 samples on the basement, 55 samples on the first floor, and 17 samples on the second floor.

Bouchard divided Dayton into regions comprised of several ZIP code areas. Survey one and Bouchard's results for each regions are in Table 7 and Table 8. Some of the regions without sufficient number of samples were left out.

Table 7. Comparison of First Survey and Bouchard's Survey by Participant's Home Region (Basement)

ZIP Codes (Regions)	Survey One's Results (pCi/l)	Bouchard's Results (pCi/l)
45432, 45459, & 45305 Miamisburg/Bellbrook	1.1 / 0.7	7.43
45432 & 45431 Beavercreek/Riverside	2.0 / 2.4	8.58

Table 8. Comparison of First Survey and Bouchard's Survey by Participant's Home Region (First Floor)

ZIP Codes (Regions)	Survey One's Results (pCi/l)	Bouchard's Results (pCi/l)
45432, 45459, & 45305 Miamisburg/Bellbrook	0.8 / 0.5	4.84
45432 & 45431 Beavercreek/Riverside	1.7 / 2.3	5.78
45424 & 45409 Huber Heights	3.2 / 2.2	4.18

Bouchard plotted the results of radon measurement on log-probability paper. The plot was a straight line; indicating a log-normal distribution of radon measurements (2:21). The plot of survey one's radon measurements are in Figure 7. The survey one's result also indicated log-normal distribution of radon measurements. The arithmetic average radon concentration and standard error of the mean of the 85 samples were 2.9 $\pm$ 0.5 pCi/l. The geometric mean was 1.5 pCi/l with geometric standard deviation of 2.7. The EPA's action level of 4 pCi/l was exceeded by 16% of the samples.

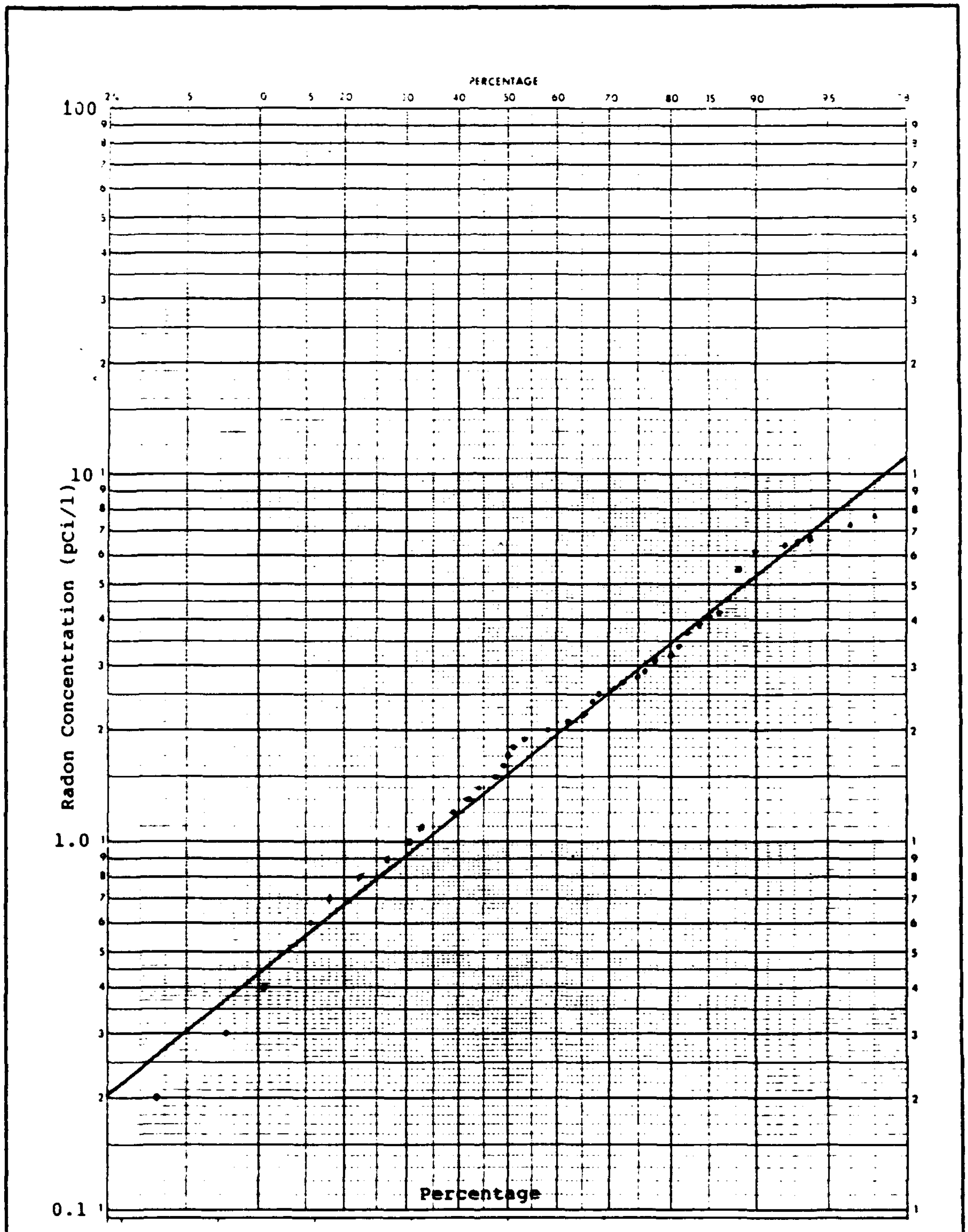

Figure 7. Distribution of Radon Measurements of All Homes from the First Survey

Questions From Survey Form Relating to the Radon Concentration. The correlations obtained from the survey are in Appendix F with the question number pertaining to the table appearing at the end of the title. The correlations are based on number of samples and the standard deviation. Questions with limited number of samples were left out of the appendix.

Huber Heights has the highest arithmetic average radon concentration at 5.4 pCi/l with standard deviation of 1.6 pCi/l. In examining the results, an unexpected result was the radon concentration in the basement. The average radon concentration in the basement was lower than rest of the house. This disparity could be due to the limited sample size. Any questions from the survey form that are heavily dependant on the basement has a relative lower reading. The average radon concentration decreased as number of stories in a building increased. The results from the survey indicate that radon concentration is affected by the contents of the home. The radon concentration was not higher in homes that used natural gas appliances. However, a home that uses an exhaust fan has a lower radon concentration. A home without a central air conditioning also has a lower radon concentration.

Second Survey of Dayton Area for Radon Concentration

The purpose of the second survey was to measure the radon concentration of Dayton area using the modified survey form. There was 156 samples taken in November from the Dayton area. The weather conditions were different then the first survey's weather conditions indicating that the results would be different then the first survey's results. A comparison was not done between Bouchard's data and the second survey's data since there was no correlation on the first survey's data. Table 28 contains the arithmetic average and standard deviation for the basement's, first floor's, and second floor's from the second survey.

Table 28. Second Survey's Results by Location of Vials in the Participants' Homes

Location of Vials	Survey Two's Results (pCi/l)	Number of Samples
Basement	7.1 / 6.7	22
First Floor	3.8 / 3.7	99
Second Floor	2.1 / 3.4	33

Survey two's results for each regions of interest are in Table 29 and Table 30.

Table 29. Second Survey's Results by Participant's Home Region (Basement)

ZIP Codes (Regions)	Survey Two's Results (pCi/l)	Number of Samples
45430, 45420, 45419, & 45409 Beavercreek/Oakwood	2.0 / 1.0	6
45432 & 45431 Beavercreek/Riverside	3.7 / 4.6	24
45324, 45435 45323, & 45387 Fairborn/Enon	9.0 / 4.9	7

Table 30. Second Survey's Results by Participant's Home Region (First Floor)

ZIP Codes (Regions)	Survey Two's Results (pCi/l)	Number of Samples
45432, 45459, & 45305 Miamisburg/Bellbrook	3.4 / 2.7	8
45440 & 45429 Kettering	4.3 / 3.1	8
45430, 45420, 45419, & 45409 Beavercreek/Oakwood	2.0 / 1.0	6
45432 & 45431 Beavercreek/Riverside	3.0 / 2.1	28
45324, 45435, 45323, & 45387 Fairborn/Enon	3.8 / 4.0	18
45424 & 45409 Huber Heights	4.7 / 4.6	31

The plot of survey two's radon measurements are in Figure 8.

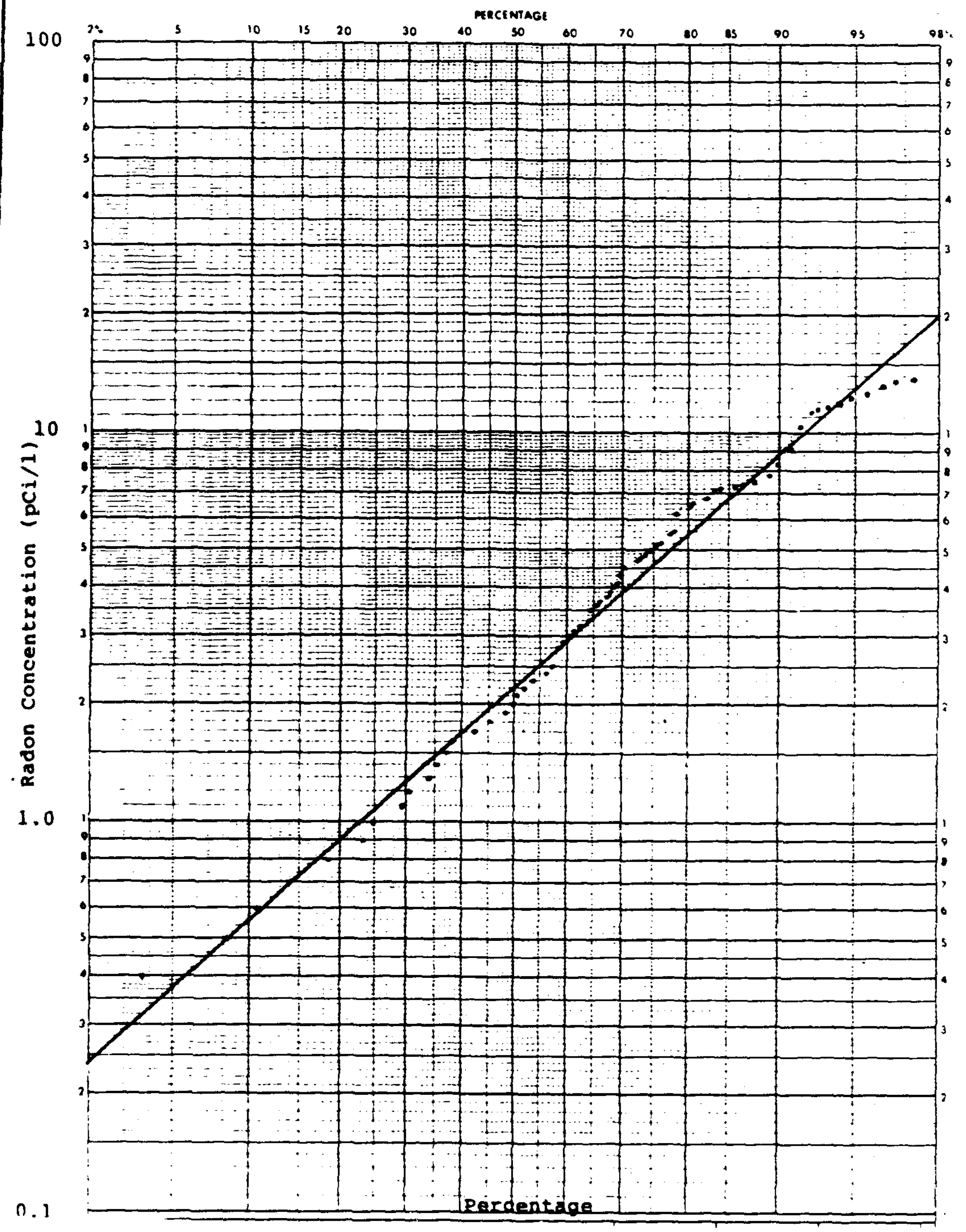

Figure 8. Distribution of Radon Measurements of All Homes from the Second Survey

The result from this survey indicates a log-normal distribution of radon measurements. The arithmetic average radon concentration and standard error of the mean of the 156 samples were 3.8 ± 0.3 pCi/l. The geometric mean was 2.2 pCi/l with geometric standard deviation of 3.0. The EPA's action level of 4 pCi/l was exceeded by 29% of the samples.

Questions From Survey Form Relating to the Radon Concentration. The correlations obtained from the survey are in Appendix G with the question number pertaining to the table appearing at the end of the title. The correlations are based on number of samples and the standard deviation. Questions with limited number of samples were left out of the appendix.

Huber Heights and Beavercreek have the highest arithmetic average radon concentration of 4.3 pCi/l and 4.3 pCi/l with standard deviation of 4.3 pCi/l and 4.9 pCi/l, respectively. The arithmetic average radon concentration in the basement is higher than any other parts of the house. The average radon concentration decreased as number of stories in a building increased.

The results from the survey indicate that radon concentration is affected by particular contents of the home. The radon concentration was not higher in homes that used natural gas appliances. However, a home that uses an exhaust fan has a lower radon concentration. Using an electrostatic precipitator also decreased the radon while use of a

humidifier does not affect the radon concentration. A home without central air conditioning also has a lower radon concentration while insulated houses have a higher reading. The results for each correlation are in the Appendix G.

Comparison of First and Second Survey

The arithmetic average radon concentrations with the standard error of the mean were 2.9 ± 0.5 for the first survey and 3.8 ± 0.3 for the second survey. The 31% increase occurred in a span of 3 months. The first survey was done in September 1991 while the second survey was done in November 1991. The straight line on log-normal probability paper shifted from September to November. The shift was due to weather change and the people changing their home environment in response to the weather changes. The shift indicates that the radon concentration changes from time to time.

VII. Conclusions and Recommendations

Conclusions

The database, set up to handle the information and the questions from the survey form, performed well. The database can generate correlations and print reports for the participants. The report provides information on EPA's recommendations.

In addition to the setting up the database, a protocol for measuring radon concentration was established based on experiments and previous research. Except for the exposure time, all the components of the original protocol was modified.

Using the new protocol, the time required for measuring radon concentration was cut by more than 50%. The analysis of the vials now take 18 hours instead of 48 hours needed in the previous theses. In addition, the conversion factor was made independent of exposure time. Previously, the conversion factor was heavily dependent on the exposure time.

With the protocol for measuring radon concentration, two surveys were conducted. First survey resulted in modification of the survey form and helped set up a procedure for conducting surveys. The second survey went much smoother with a larger number of participants. The results from two surveys revealed time and spatial dependence of radon concentration.

The log-normal distribution of radon concentrations were also observed in the surveys.

Recommendations

Recommendations to improve the equation of conversion, the database, and the survey form are as follows:

1. Finish the EPA's RMP Program. Currently, AFIT is in the process of finishing the program. The tests from the program will occur in 1992.

2. The survey form should be modified as more surveys are taken.

3. As the survey form changes, Reflex structure for radon analysis needs to be modified.

4. Write a program to plot the results of radon concentration on a log-probability paper. Presently, the results are plotted manually.

5. An epidemiological study can be accomplished using the protocol for measuring radon concentration. The database can easily be modified to do an epidemiological study.

Appendix A. Instructions for Use of LS Analyzer

For ease of readability and usability, the instructions are in a list format.

1. Preparation of Vials
   - Expose the vial for 48 hours
   - Add 10 ml of InstaFluor
     - -- pour InstaFluor without touching the charcoal
   - Add 10 ml of InstaFluor to an unexposed vial
     - -- used as a background count
   - Wait for a minimum of 18 hours for elution time

2. Preparation of the Varisette Cassettes
   - Find a cassette with a Protocol plug or put a Protocol plug into the cassette
   - Push the Cycle Reset Flag (on Protocol plug) outward
     - -- Analyzer will not count the vials if this is not accomplished
   - Put the Background vial in the first position
   - Put the samples (vials) behind the background vial
     - -- If there are more than 11 vials, use an empty cassette and place it behind the first cassette

3. **Procedure for Defining Protocols for Counting the Vials**

- Protocols 3, 4, 6, and 8 are ready for use
- For new protocols:
  - -- Start at "Status Page" screen (usual position)
  - -- Press "F1" for "Edit Protocol" screen
  - -- Press protocol number for editing for "CPM Page" screen
  - -- * USE copy protocol # to copy 3, 4, 6, or 8 *

    OR
  - -- Type in desired protocol name
  - -- Set cycle = 1
  - -- Set count time = 10
  - -- Set 2 sigma coincidence = no
  - -- Set # Count/Vial = 1
  - -- Set # Vials/Standard = 1
  - -- Set # Vials/Sample = 1
  - -- Set 1st Vial Background = yes
  - -- Set Region A, B, or C for 25 keV to 900 keV
  - -- Press "PgDn" for "Additional Features" screen
  - -- Set half-life = 0 (Skip Ref Date and Time)
  - -- Set other questions in the page to no
  - -- Press "PgDn" for "Print Format" screen
  - -- Enter comments in additional heading
  - -- In Print Cells, select desired cell number to print (definitely need cpm in region of interest)
  - -- Press "F2" to exit edit

4. Press "F2" in "Status Page" screen to start counting

Note : If the user does not want to use the background vial do to small number of cells :

- Skip adding InstaFluor to the unexposed vial
- Set 1st Vial Background = no
- In the Region of interest enter the known background count

Appendix B. Reply Letter for Low Radon Concentration

Lt. Taewon Kim
AFIT/GNE-92M
P.O. Box 4087
WPAFB, OH 45433
513-255-7228

[Date]

To : [Last Name]
: [AFIT Box]

The results of your radon survey are as follows:

Location of Vial	Concentration
xxxxxxx	x.x
xxxxxxx	x.x

None of the radon concentrations in the samples from your building exceeded the EPA's action level of 4 pCi/liter.

Please keep in mind that this is only a preliminary test, it's purpose is to suggest whether radon is a problem. Radon levels vary with time of day and especially over the year. Consequently, additional tests would be required to determine the average concentration during the year and there by assess whether the average exceeds the EPA's action level of 4 pCi/liter.

Thank you for participating in this survey. If you have any questions or comments, please contact me or my advisor, Dr. George John, AFIT/GNE, 255-4498.

Sincerely,

Taewon Kim

AFIT/GNE-92M

Appendix C. Reply Letter for High Radon Concentration

Lt. Taewon Kim
AFIT/GNE-92M
P.O. Box 4087
WPAFB, OH 45433
513-255-7228

[Date]

To : [Last Name]
: [AFIT Box]

The results of your radon survey are as follows:

Location of Vial	Concentration
xxxxxxx	x.x
xxxxxxx	x.x

The EPA has set a maximum radon concentration of 4 pCi/liter for any building which you occupy 75% of the time. At least one of the samples taken in your building read higher.

Please keep in mind that this is only a preliminary test; radon levels vary with time of day and especially over the year. No drastic action should be taken on any results given here. If your building measured above the EPA's maximum in a working or living area, it is recommended that you have additional testing done including an average reading over an entire year.

The EPA considers radon concentration of 4 pCi/liter to 20 pCi/liter to be above average for the residential structure. They recommend that you take action to reduce the concentration to below 4 pCi/liter within a few year.

If the concentration exceeds 20 pCi/liter, you should take action within several months to reduce it.

Thank you for participating in this survey. If you have any questions or comments please contact me or my advisor, Dr. George John, AFIT/GNE, 255-4498.

Sincerely,

Taewon Kim
AFIT/GNE-92M

Appendix D. Instruction for Use of Reflex Database

For ease of readability and usability, the instructions are in a list format. In "Select", each menu items must be done in order it is presented.

1. Start the Program,

   - Enter the directory Reflex software is in
   - Type Reflex [filename of program]
     - -- first survey is under "radon" filename
     - -- second survey is under "radon2" filename
     - -- just for conversion of cpm to pCi/l, use "radbak"
   - A new database can be started by copying a file under a new name and then deleting all the old records

2. Add a New Record

   - Select Views/Form/Datamode
   - Press Shift-F8, F8 to get to the end of datafile
   - Enter answers for each questions

3. Change or View Records

   - Select Views/Form/Datamode
   - Use F7 for previous record

     F8 for next record

     Shift-F7 for first record of the database

     Shift-F8 for last record of the database

- Use the arrow keys to view the record
- To change the record, overwrite the old data with new

4. Modify the Structure of the Record
   - Add a field*
     -- Select Database/Add a Field.. or press F4
     -- Type in the field name
   - Delete a field
     -- Select Database/Field Properties.. or Shift-F4
     -- Press F3
     -- Select the field by using a mouse or arrows
     -- Press Del key
   - Move a field in record structure
     -- Select Views/Form/Design
     -- Highlight the field of interest
     -- Select Edit/Move
     -- Move into new position and press Enter

5. Delete a Record
   - Select Views/Form/Datamode
   - Find the record using F7, F8, Shift-F7, or Shift-F8
   - Select Records/Delete Record

   ** Caution : Once a record is deleted, it can not be brought back except by reentering the record

* Structure is composed of fields. Each field contains an information from the survey.

6. Graphical Results

- Works for one to one correlation unless using filter
- Select View/Graph
- Select Graph/Graph Type and Layout..
  - -- Pick Graph Type = bar
  - -- Press Proceed
- Highlight X-axis field (below the x-axis)
  - -- Type in the field of interest

    or

  - -- Press right mouse button and select a field
- Highlight Y-axis field (bottom screen)
  - -- Type in @AVG(Concentration)
  - -- Summary functions; Standard Deviation (@std), Number of Records (@count), Maximum (@max), Minimum (@min), and Variance (@var) can be used concurrently or singularly

7. Tabular Results

- Select Views/Xtab
- Highlight Field
  - -- Type in Concentration
- Highlight Rows
  - -- Type in field of interest

    or

  - -- Press right mouse button and select a field

- Make sure Column is empty for one to one correlation
    - -- Summary functions can be used in Column by entering it in Summary field or typing in the summary function in the Column
- ** For cross referencing two fields
    - -- Highlight Column and enter field name
- ** For cross referencing three or more fields
    - -- Select Xtab/Xtab filter
        - --- add conditions to filter out unwanted records

8. Quit Reflex

- Select Database/Quit or Alt-Q

INSTRUCTIONS FOR USING "RADON VIAL"

1. You have received 2 vials:	do not test during high winds keep doors and windows closed during the test.
2. If you have a basement:	put 1st vial in the basement (by a sump or a drain) and 2nd vial in the family room.
If no basement:	put 1st vial in the family room and 2nd vial in the bedroom.
3. Place the vials:	on a stand, a table, or a shelf at least 1 ft. from any wall away from windows or drafts.
4. To start the test:	remove the cap from the vial place the cap next to the vial.

5. PRINT the serial number, the location, the time, and the date of the opening in the space provided below.

6. Leave the vial undisturbed for two days (48 hours).

7. To end the test, replace the cap on the vial tightly.

8. PRINT the time and date that you sealed the vial in the space provided below.

9. **Return the vial AS SOON AS POSSIBLE, preferably on the same day, or within 24 hours at the latest.**

PROVIDE THE INFORMATION REQUESTED BELOW

NAME____________________ AFIT BOX____________________
ADDRESS____________________ PHONE____________________
CITY, ZIP____________________

1st VIAL: SERIAL # ________________ LOCATION ________________

2nd VIAL: SERIAL # ________________ LOCATION ________________

OPENED: DATE ________________ TIME ________________ am/pm

CLOSED: DATE ________________ TIME ________________ am/pm

The following questionnaire is designed to provide information pertinent to radon hazard sources, risks, and possible mitigation. Please answer all questions as completely and truthfully as possible. All responses will be kept in the strictest confidence, and used only for our studies.

1. Which of the following best describes this building?
   a. Multi-unit building
   b. Single-unit building
   c. Mobile home

2. How many stories does your house have? ____________________

3. Approximately how many square feet of floor space is there on the bottom story or basement of your home? ________________

4. How old is your house? ________________ yrs.

5. Does your house have a full or partial basement, a cellar, or a level which has one or more walls partially or completely below ground level? Such a level will be considered a basement. Note: If the answer to this question is no, skip to question 9.
   a. Yes
   b. No

6. What best describes the material makeup of the outside walls of the basement ?
   a. Concrete block or cinder block
   b. Poured concrete
   c. Stone and mortar
   d. Wood
   e. Brick or brick veneer
   f. Earth, dirt, clay, etc.

7. Describe the approximate percentage of each type of treatment of the inside of the outer walls of the basement:
   a. ___% Untreated
   b. ___% Panelling without insulation
   c. ___% Panelling with insulation
   d. ___% Paint
   e. ___% Sealant or airtight paint
   f. ___% Other (describe) ______________________

8. Is any part of the basement floor exposed earth?
   a. Yes
   b. No

9. Are there any unsealed passages between the basement or crawl space and the interior of the house?
   a. Yes
   b. No

10. Is the primary heating system in the basement or crawl space?
   a. Yes
   b. No

11. Is there a sump pump in the main drain for the basement or crawl space?
   a. Yes
   b. No

12. What percentage of your house is over a...
   a. Basement.............. _____%
   b. Concrete slab......... _____%
   c. Crawl space........... _____%
   d. Open air.............. _____%
   e. Something else........ _____% (describe) ______

13. Describe any other concrete or asphalt surfaces attached to or bordering the foundation:
   a. None
   b. Driveway
   c. Parking structure or carport
   d. Patio
   e. Loading ramp
   f. Other (describe) _________________

14. What type of distribution system is used for primary heat?
   a. Forced air
   b. Hot water or steam (radiator, baseboard)
   c. Natural convection (fireplace, woodstove, etc.)
   d. Other (describe) _________________

15. What fuel is used for primary heating?
    a. Natural gas
    b. Electricity
    c. Oil
    d. Coal
    e. Propane or bottled gas
    f. External steam source
    g. Wood
    h. Other (describe) ________________

16. Is any part of your house excluding the basement built on a concrete slab?
    a. Yes
    b. No

17. If the primary heat source is some kind of combustion, is outside air brought in to replace the exhaust going up through the chimney?
    a. Yes
    b. No
    c. N/A

18. Is there an air-to-air heat exchanger or heat-recovery ventilator in this house? (Note: Such a system blows stale air out of the building, brings in fresh air from outside, and transfers heat from the stale air to the fresh air.)
    a. Yes
    b. No

19. Does your house the public water supply, or is the water drawn from a private well?
    a. Public water supply
    b. Private well

20. Does your house have any of the following gas or propane fueled appliances?
    a. Water heater
    b. Clothes dryer
    c. Stove/Oven
    d. Refrigerator
    e. Air conditioner
    f. Heat pump
    g. Fork Lift
    h. Other (describe) ________________________

21. Does your house have central air conditioning?
    a. Yes
    b. No

22. Does your house have any of these other A/C systems?
   a. Window or wall-mounted units
   b. Swamp or evaporative coolers
   c. None

23. Is your ceiling insulated?
   a. Yes
   b. No

24. Are the walls insulated?
   a. Yes
   b. No

25. Overall, how tightly sealed is your house?
   a. Tightly
   b. Moderately
   c. Leaky

26. Considering both heating and cooling seasons, about how many months of the year is house sealed up, that is, windows and doors usually closed? __________

27. If your house has an exhaust fan which blows air outside, how often is it used during the cooling season?
   a. Continuously
   b. Moderately
   c. Infrequently
   d. N/A

28. If your house has an electrostatic precipitator (i.e. electric air cleaner), how often is it used?
   a. Continuously
   b. Moderately
   c. Infrequently
   d. N/A

29. If your house has a humidifier, how often is it used?
   a. Continuously
   b. Moderately
   c. Infrequently
   d. N/A

Appendix F. Results of First Dayton Area Survey*

Table 9. ZIP Code and Average Radon Concentration (pCi/l)

ZIP Code	Rn Conc. / STD	Number of Samples
45324	2.7 / 0.9	7
45424	3.2 / 2.2	20
45431	2.1 / 2.6	19
45432	1.1 / 0.7	10

Table 10. Cities and Average Radon Concentration (pCi/l)

City	Rn Conc. / STD	Number of Samples
Beavercreek	1.3 / 0.7	12
Dayton	1.5 / 0.7	16
Fairborn	3.1 / 3.1	12
Huber Heights	5.4 / 7.2	22
Kettering	4.3 / 3.1	6

Table 11. Location of the Vials and Average Radon Concentration (pCi/l)

Location	Rn Conc. / STD	Number of Samples
Basement	2.0 / 1.6	12
Bedroom	5.1 / 7.7	12
Family Room	2.0 / 0.7	6
Kitchen	1.6 / 1.3	7
Living Room	3.8 / 5.8	16

* Some tables were omitted due to limited number of samples. Rn Conc. is arithmetic average and STD is standard deviation.

Table 12. Location (Which Floor) and Average Radon Concentration (pCi/l)

Floor	Rn Conc. / STD	Number of Samples
Basement (0)	2.2 / 1.6	13
1	3.4 / 5.2	55
2	1.9 / 2.0	17

Table 13. Type of Building and Average Radon Concentration (pCi/l) (1)

Type	Rn Conc. / STD	Number of Samples
Single-unit	1.7 / 1.6	38
Multi-unit	4.0 / 5.6	45

Table 14. Number of Stories in the Building and Average Radon Concentration (pCi/l) (2)

Stories	Rn Conc. / STD	Number of Samples
1	5.2 / 6.7	27
2	2.1 / 1.9	45
3	0.8 / 0.5	11

Table 15. Presence of Basement and Average Radon Concentration (pCi/l) (5)

Basement	Rn Conc. / STD	Number of Samples
no	3.5 / 5.1	58
yes	1.8 / 1.4	25

Table 16. Existence of Unsealed Passages and Average Radon Concentration (pCi/l) (9)

Unsealed Passages	Rn Conc. / STD	Number of Samples
no	1.4 / 0.8	15
yes	2.4 / 1.6	12

Table 17. Existence of Sump Pump and Average Radon Concentration (pCi/l) (11)

Sump Pump	Rn Conc. / STD	Number of Samples
no	2.4 / 2.2	60
yes	1.3 / 0.8	12

Table 18. Foundation of the House and Average Radon Concentration (pCi/l) (12)

Foundation	Rn Conc. / STD	Number of Samples
Basement	1.7 / 1.4	25
Concrete	3.7 / 5.2	54

Table 19. Existence of the Concrete or Asphalt Around the House and Average Radon Concentration (pCi/l) (13)

Concrete/ Asphalt	Rn Conc. / STD	Number of Samples
no	1.8 / 0.9	10
yes	3.1 / 4.6	73

Table 20. Fuel for Primary Heating and Average Radon Concentration (pCi/l) (15)

Fuel	Rn Conc. / STD	Number of Samples
electricity	4.2 / 6.9	26
natural gas	2.4 / 2.4	53

Table 21. House on Concrete and Average Radon Concentration (pCi/l) (16)

House on Concrete	Rn Conc. / STD	Number of Samples
no	3.8 / 7.6	21
yes	2.7 / 2.4	61

Table 22. Outside Air Brought In for Combustion and Average Radon Concentration (pCi/l) (17)

Air Brought In	Rn Conc. / STD	Number of Samples
N/A	2.1 / 1.8	27
no	2.8 / 2.7	35
yes	1.8 / 1.4	19

Table 23. Existence of Heat Exchanger and Average Radon Concentration (pCi/l) (18)

Heat Exchanger	Rn Conc. / STD	Number of Samples
no	3.1 / 4.6	75
yes	1.3 / 1.1	8

Table 24. Water Supply and Average Radon Concentration (pCi/l) (19)

Water Source	Rn Conc. / STD	Number of Samples
Private	3.9 / 1.9	5
Public	2.9 / 4.6	76

Table 25. Number of Gas Appliances and Average Radon Concentration (pCi/l) (20)

Number of Gas Appliances	Rn Conc. / STD	Number of Samples
0	3.6 / 6.3	32
1	3.0 / 2.8	31
2	1.9 / 1.5	16

Table 26. Existence of Central Air Conditioning and Average Radon Concentration (pCi/l) (21)

Central Air Conditioner	Rn Conc. / STD	Number of Samples
no	1.5 / 0.7	6
yes	3.1 / 4.5	77

Table 27. Tightness of the House and Average Radon Concentration (pCi/l) (25)

Tightness of the House	Rn Conc. / STD	Number of Samples
Leaky	2.8 / 3.5	9
Moderate	3.6 / 5.1	53
Tight	1.4 / 0.9	17

Appendix G. Results of Second Dayton Area Survey*

Table 31. ZIP Code and Average Radon Concentration (pCi/l)

ZIP Code	Rn Conc. / STD	Number of Samples
45324	3.3 / 3.7	34
45410	3.1 / 2.8	10
45424	4.3 / 4.4	40
45431	2.7 / 1.8	22
45432	5.6 / 6.9	10

Table 32. Cities and Average Radon Concentration (pCi/l)

City	Rn Conc. / STD	Number of Samples
Beavercreek	4.3 / 4.9	24
Dayton	3.1 / 4.2	38
Fairborn	3.4 / 3.6	36
Huber Height	4.3 / 4.4	40
Kettering	3.3 / 3.2	6

Table 33. Location of the Vials and Average Radon Concentration (pCi/l)

Location	Rn Conc. / STD	Number of Samples
Basement	7.1 / 6.7	22
Bedroom	3.5 / 3.7	51
Family Room	3.2 / 3.4	75

* Some tables were omitted due to limited number of samples. Rn Conc. is arithmetic average and STD is standard deviation.

Table 34. Location (Which Floor) and Average Radon Concentration (pCi/l)

Floor	Rn Conc. / STD	Number of Samples
Basement (0)	7.1 / 6.7	22
1	3.8 / 3.6	99
2	2.1 / 2.7	33

Table 35. Type of Building and Average Radon Concentration (pCi/l) (1)

Type	Rn Conc. / STD	Number of Samples
Single-unit	5.4 / 5.1	84
Multi-unit	2.1 / 1.8	72

Table 36. Number of Stories in the Building and Average Radon Concentration (pCi/l) (2)

Stories	Rn Conc. / STD	Number of Samples
1	5.6 / 5.0	54
2	2.7 / 3.4	88
3	3.9 / 3.8	14

Table 37. Square Feet of the Lowest Floor of Building and Average Radon Concentration (pCi/l) (3)

Square Feet	Rn Conc. / STD	Number of Samples
0 to 499	2.9 / 2.3	12
500 to 999	2.4 / 2.4	62
1000 to 1499	4.5 / 4.6	62
1500 and UP	5.8 / 4.8	18

Table 38. Age of the Building and Average Radon Concentration (pCi/l) (4)

Age of House (Years)	Rn Conc. / STD	Number of Samples
0 to 9	2.1 / 2.3	58
10 to 19	5.0 / 5.9	26
20 to 29	4.1 / 3.0	38
30 to 39	7.3 / 5.0	10
40 to 49	6.6 / 6.6	12
50 to 59	2.6 / 2.2	8

Table 39. Presence of Basement and Average Radon Concentration (pCi/l) (5)

Basement	Rn Conc. / STD	Number of Samples
no	3.5 / 3.7	106
yes	4.5 / 5.3	50

Table 40. Material Makeup of Basement's Outer Wall and Average Radon Concentration (pCi/l) (6)

Material	Rn Conc. / STD	Number of Samples
Concrete or Cinder Block	3.5 / 2.3	20
Poured Concrete	5.7 / 6.7	26

Table 41. Treatment of the Walls of Basement and Average Radon Concentration (pCi/l) (7)

Treatment	Rn Conc. / STD	Number of Samples
Paint	3.4 / 3.1	24
Panelling with Insulation	5.9 / 6.7	10
Panelling without Insulation	4.3 / 5.1	6
Untreated	5.7 / 7.7	8

Table 42. Presence of Exposed Earth in the Basement and Average Radon Concentration (pCi/l) (8)

Exposed Earth	Rn Conc. / STD	Number of Samples
no	4.9 / 5.8	40
yes	2.8 / 1.1	10

Table 43. Existence of Unsealed Passages and Average Radon Concentration (pCi/l) (9)

Unsealed Passages	Rn Conc. / STD	Number of Samples
no	3.2 / 3.6	134
yes	7.4 / 6.0	22

Table 44. Existence of Primary Heating System in the Basement and Average Radon Concentration (pCi/l) (10)

System in Basement	Rn Conc. / STD	Number of Samples
no	3.4 / 3.7	108
yes	4.7 / 5.3	48

Table 45. Existence of Sump Pump and Average Radon Concentration (pCi/l) (11)

Sump Pump	Rn Conc. / STD	Number of Samples
no	3.7 / 4.0	144
yes	4.8 / 6.3	12

Table 46. Foundation of the House and Average Radon Concentration (pCi/l) (12)

Foundation	Rn Conc. / STD	Number of Samples
Basement	4.8 / 5.6	42
Concrete	3.4 / 3.4	104
Crawl Space	5.9 / 4.4	8

Table 47. Existence of the Concrete or Asphalt Around the House and Average Radon Concentration (pCi/l) (13)

Concrete/ Asphalt	Rn Conc. / STD	Number of Samples
no	2.0 / 2.0	16
yes	4.0 / 4.4	140

Table 48. Fuel for Primary Heating and Average Radon Concentration (pCi/l) (15)

Fuel	Rn Conc. / STD	Number of Samples
electricity	3.3 / 3.5	56
natural gas	4.1 / 4.8	92
oil	4.7 / 2.3	8

Table 49. House on Concrete and Average Radon Concentration (pCi/l) (16)

House on Concrete	Rn Conc. / STD	Number of Samples
no	3.5 / 4.3	46
yes	4.0 / 4.3	110

Table 50. Outside Air Brought In for Combustion and Average Radon Concentration (pCi/l) (17)

Air Brought In	Rn Conc. / STD	Number of Samples
N/A	3.4 / 3.3	72
no	4.1 / 4.8	52
yes	4.3 / 5.1	32

Table 51. Existence of Heat Exchanger and Average Radon Concentration (pCi/l) (18)

Heat Exchanger	Rn Conc. / STD	Number of Samples
no	3.9 / 4.3	144
yes	2.6 / 3.1	12

Table 52. Number of Gas Appliances and Average Radon Concentration (pCi/l) (20)

Number of Gas Appliances	Rn Conc. / STD	Number of Samples
0	3.7 / 3.6	66
1	4.6 / 5.3	62
2	2.5 / 2.6	26

Table 53. Existence of Central Air Conditioning and Average Radon Concentration (pCi/l) (21)

Central Air Conditioner	Rn Conc. / STD	Number of Samples
no	3.3 / 3.6	26
yes	3.9 / 4.4	130

Table 54. Other Types of Air Conditioners and Average Radon Concentration (pCi/l) (22)

Air Conditioners	Rn Conc. / STD	Number of Samples
none	4.0 / 4.4	132
Window or Wall Units	3.2 / 3.7	22

Table 55. Existence of Insulation in the Ceiling and Average Radon Concentration (pCi/l) (23)

Insulated Ceiling	Rn Conc. / STD	Number of Samples
no	1.8 / 1.1	10
yes	4.0 / 4.4	146

Table 56. Existence of Insulation in the Walls and Average Radon Concentration (pCi/l) (24)

Insulated Walls	Rn Conc. / STD	Number of Samples
no	3.1 / 3.3	14
yes	3.9 / 4.4	142

Table 57. Tightness of the House and Average Radon Concentration (pCi/l) (25)

Tightness of the House	Rn Conc. / STD	Number of Samples
Leaky	3.9 / 4.8	26
Moderate	4.4 / 4.3	88
Tight	2.5 / 3.4	42

Table 58. Months the House is Sealed and Average Radon Concentration (pCi/l) (26)

Months House is Sealed	Rn Conc. / STD	Number of Samples
3	1.7 / 1.8	6
4	4.2 / 2.6	8
5	2.1 / 2.1	18
6	4.1 / 3.9	30
7	4.6 / 6.2	14
8	5.2 / 4.2	24
9	2.1 / 1.2	18
10	3.5 / 3.9	16
12	4.1 / 4.7	16

Table 59. Usage of Exhaust Fan and Average Radon Concentration (pCi/l) (27)

Exhaust Fan Usage	Rn Conc. / STD	Number of Samples
infrequently	3.2 / 3.3	28
moderately	3.2 / 2.4	20
N/A	4.2 / 4.7	106

Table 60. Usage of Humidifier and Average Radon Concentration (pCi/l) (29)

Humidifier Usage	Rn Conc. / STD	Number of Samples
continuously	4.1 / 3.9	10
moderately	5.5 / 4.5	10
N/A	3.7 / 4.3	132

Bibliography

1. Bodansky, David. "Overview of the Indoor Radon Problem." Indoor Radon and Its Hazards. edited by Davitd Bodansky and others. Seattle: University of Washington Press, 1987.

2. Bouchard, Capt. Joseph P. Development of Techniques to Relate Radon Levels in Homes in the Dayton Area to Local Geology and Fill Material. MS Thesis, AFIT/GNE/ENP/88M-2. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1988.

3. Cothern, C. R. "Properties." Environmental Radon. edited by C. Richard Cothern and James E. Smith, Jr. New York: Plenum Publishing Corp., 1987.

4. Jenkins, Phillip H. "Equations for Calculating Radon Concentration Using Charcoal Canisters." Health Physics, 61: 131-136 (July 1991).

5. Kessler, Michael J. Liquid Scintillation Analysis : Science and Technology. Packard Instrument Company, 1988.

6. Packard Instrument Company. "PICO-RAD Radon Analysis Software Operation Manual." Packard Instrument Company, 1988.

7. Packard Instrument Company. "Tri-Carb Liquid Scintillation Analyzers Operation Manual." Packard Instrument Company, 1988.

8. Pierce, William D. Development of a System to Perform, Record, and Analyze Measurements of Radon Concentrations on a Large Scale. MS Thesis, AFIT/GNE/ENP/90D-4. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December 1990.

9. Robkin, Maurice A. "Terminology for Describing Radon Concentrations and Exposures." Indoor Radon and Its Hazards. edited by Davitd Bodansky and others. Seattle: University of Washington Press, 1987.

10. Sharp, Capt. David L. Evaluation of Three Passive-Integrating Charcoal Detectors for Measuring Radon Concentrations. MS Thesis, AFIT/GNE/ENP/90M-6. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1990.

11. U.S. Department of Energy. Radon : Indoor Radon and Decay Products : Concentrations, Causes, and Control Strategies. DOE/ER-0480P. National Technical Information Service, November 1990.

12. United States Environmental Protection Agency. "Questionnaire The National Residential Radon Survey." March 20, 1989.

13. United States Environmental Protection Agency and U.S. Department of Health and Human Services. A Citizen's Guide to Radon. OPA-86-004. U.S. Government Printing Office: 1989.

14. Wharton, Capt. Randy R. An Enviromentally Controlled Chamber for the Study of Radon Detection. MS Thesis, AFIT/EN/GNE/91M-11. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1991.

Vita

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13. ABSTRACT *(Maximum 200 words)* A system to do a large scale survey was developed. The data obtained from the survey was analyzed using a database. The database incorporated an equation for converting cpm into radon concentration (pCi/l). The equation of conversion, protocol for measuring radon concentration, survey form, and a database program were modified (from previous theses) or developed for this thesis. The elution time constant, adsorption time constant, and calibration factor were calculated for equation of conversion.

Two surveys were during the course of the thesis. On the first survey, the arithmetic average radon concentration with standard error of the mean was 2.9 + 0.5 pCi/l. The geometric mean (G.M.) was 1.5 pCi/l with geometric standard deviation of 2.7 pCi/l. There were 85 samples taken during the first survey. On the second survey, with 156 samples The arithmetic average and std. deviation was 3.8 + 0.3 pCi/l. The G.M. was 3.8 pCi/l with geometric std. deviation of 2.2 pCi/l. The second survey was done during winter using a modified survey form. The results from both surveys indicated a log-normal distribution.

The system is in process of begin certified by the EPA. The system is ready to be used for larger scale survey.

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